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PRODUCTION ENHANCEMENT AND OPERATION PARAMETER'S OPTIMIZATION OF THE FLASH SMELTING FURNACE BASED ON NUMERICAL SIMULATION

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ABSTRACT

An extensive study of the copper flash smelting furnace has been undertaken. It aims at increasing the throughput of the flash smelting furnace and improving the smelting performance. In this paper a mathematical model, which incorporates the transport of momentum, heat and mass and reaction kinetics between gas and particles and reactions between gas and gas, is employed to simulate the phenomena in flash smelting furnace. After numerical simulation and optimization, a set of good operation parameters, which can increase production safely and efficiently, was achieved. And "the rule of 3C" was found to be a very valid method to improve the smelting performance. The optimization took a notable effect in Jinlong flash smelting furnace.

Key word: Simulation, Numerical, Flash smelting furnace, Optimization

NOMENCLATURE

A_d	profile area of the particle
C_D	particle drag coefficient
C_{pp}	specific heat capacity of the particle
g	gravity vector
h	gas specific enthalpy
H_c	convective heat source
H_r	radiative source
H_s	chemical reaction heat source
k	turbulent kinetic energy
m_p	mass of the particle
S_Φ	source term for variable Φ
T_p	temperature of particle
u	gas velocity component
v	particle velocities
Y	gas mass fraction.
Φ	variable
ρ	density of the fluid
Γ_Φ	exchange coefficient for variable Φ
ε	dissipation rate of turbulent kinetic energy

INTRODUCTION

Flash smelting process, developed by Outokumpu, is considered to be one of the most important innovations in copper metallurgy in the 20 century. In flash smelting process, the concentrate, along with recycled dust, flux, is fed into the vertical reaction shaft from the CJD burner, where the oxygen-enriched air is injected too. In the reaction shaft (RS) the particles are quickly dispersed and heated by the RS wall and the gas until decomposition. Then, the concentrate particles react with gas phase to predetermined oxidation degree. After the reaction shaft, the concentrate disengage from the gas stream and form the slag and mate layers on the bottom of the settler. Gas stream leaves the furnace via the uptake and pass through a waste heat boiler (WHB) and electrostatic precipitators (EP) before passing to a acid plant.

Today, more throughputs are demanded by metallurgical plants in order to meet the need of modernization and increasing capacities and process intensity. Some examples of increased capacity are shown in the Table 1 and the data shown in the table 1 are not the maximum obtainable capacity increases [1]. There is still a great potential for increasing capacities, process intensity, energy saving and increasing the life time of concentrate burner and reaction shaft.

Numerical simulation has effectively improved our understanding of the phenomena about flash smelting [2-9]. It can handle the complications of two-phase flow of particles and gas and chemical reactions, and consider heat and mass transfer, turbulence and radiation, and the consequences of high temperature. And it is also used to optimize the design of concentrate burner [10].

Smelter	Country	Production(% of Original capacity)
Huelva	Spain	More than 400
Harjavalta	Finland	More than 300
Saganoseki	Japan	More than 300
Tamano	Japan	More than 200
Hamburg	Germany	More than 200
Kosaka	Japan	More than 200
Guixi	China	More than 150
Toyo	Japan	More than 150
Hidalgo	United States	More than 150
Onsan	South Korea	More than 150
Olympic Dam 1	Australia	More than 150

Table 1: Examples of capacity increase of some flash smelters

MATHEMATICAL MODEL

Basic Model

To describe the phenomena occurring in flash smelting furnace, the conservation equation for the transport of mass, momentum and energy are written for each phase. The gas phase is viewed from an Eulerian framework and all the gas-phase governing equations were written in general form [5]:

$$\frac{\partial \rho \Phi}{\partial t} + div(\rho u \bullet \Phi) - div(\Gamma_\Phi grad\Phi) = S_\Phi \quad (1)$$

In the present modeling, the thirteen equations were solved (Φ =1, u, v, w, k, ε, h, Y_{O2}, $Y_{S2,}$ Y_{SO2}, Y_{CO2}, Y_{H2O}, Y_{oil}) in a steady state problem.

The particle phase is viewed from a Largrangian framework and the momentum equation for a particle moving in a surrounding fluid is given by

$$m_p \frac{dv}{dt} = C_D \rho (u - v) | u - v | A_d / 2 + m_p g \qquad (2)$$

The energy equation for a single particle in the presence of convective, radiative and chemical reaction sources is given as follows:

$$m_p C_{pp} \frac{dT_p}{dt} = H_c + H_r + H_s \qquad (3)$$

Copper concentrate combustion

In order to create a comprehensive mathematic model, a sub model is necessary to be created and integrated into the basic model. The sub model is required to describe the decomposition and combustion of the concentrate, labile sulfur's combustion and ancillary oil combustion in flash smelting furnace.

A) The decomposition reactions occur after particles reaching the decomposition temperature. The decomposition reactions are endothermic and produce the intermediate products FeS and S_2.

$$FeS_2 = FeS + 1/2\ S_2 \qquad (4)$$

$$2CuFeS_2 = Cu_2S + 2FeS + 1/2S_2 \qquad (5)$$

B) The labile sulfur from the chalcopyrite and pyrite combusts with the oxygen and releases heat to the gas phase, reaction heat is released to the gas; Partial FeS combusts with the oxygen and products FeO and SO_2. At the same time, reaction releases heat to the particles directly;

C) Slag blow reaction.

$$S_2 + 2O_2 = 2SO_2 \qquad (6)$$

$$FeS + 3/2O_2 = FeO + SO_2 \qquad (7)$$

D) Slag blow reaction.

$$FeO + 2SiO_2 = FeO\ (SiO_2)_2 \qquad (8)$$

Oil is necessary when the combustion heat of concentrate could not meet the need of the flash smelting process.

$$C_xH_y + (x+y/4)O_2 = xCO_2 + y/2H_2O \qquad (9)$$

SOLUTION ALGORITHM

Figure 1 shows the overall PSIC strategy to solve the gas and particle equations. All input data were read including details of gas and particle compositions, particle sizes, boundary conditions and properties of particle and gas. A first assumption of the source terms in the gas phase equations to zero is made, and gas equations are solved in Eulerian framework under this assumption. When the Eulerian equations are converged, the particle equations are calculated in Lagrangian framework and the reactions of particle are calculated. New source terms for all gas phase equations are computed and these source terms are under-relaxed before returning to the Eulerian calculations. One cycle of the algorithm in which the Eulerian calculations are converged and the Lagrangian calculations compute the new source terms is called a particle-iteration. Overall convergence is achieved when the source terms do not change from one particle-iteration to the next.

The numerical simulation of the flash smelting process was carried out with CFX-4, which is a general-purpose commercial CFD code for fluid flow, heat transfer and combustion processes..

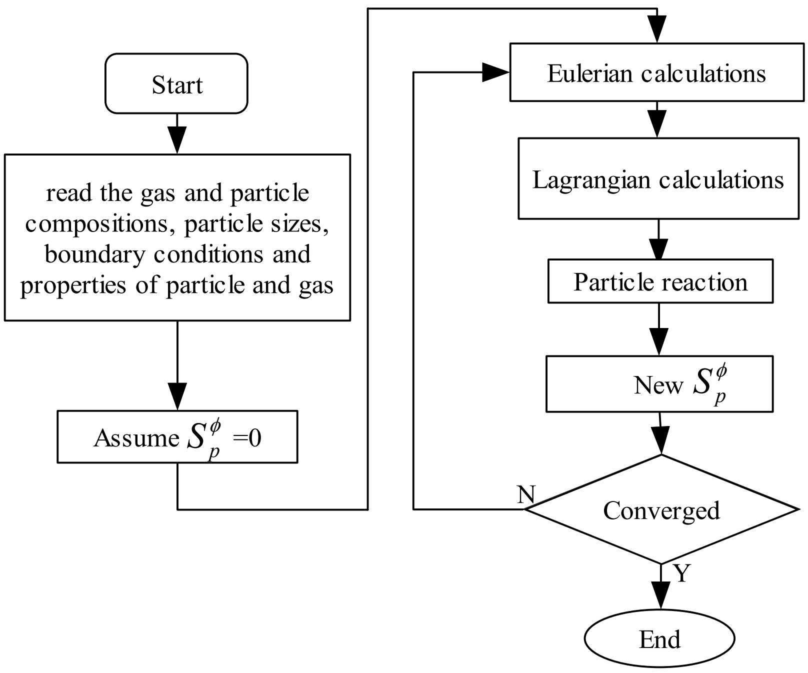

Figure 1: Overall solution algorithm of the mathematical model

SIMULATION AND OPTIMIZATION

The shaft of Jinlong smelting furnace is 5m in diameter and 6.64m tall from the top of the shaft to the bottom. The height from the bottom of shaft to the matte surface is 1.5m. A central jet distributor (CJD) burner is put at the top of the reaction shaft where the concentrate is fed into RS.

The components and the chemical analyses of concentrate are showed in table2. Table 3 gives the diameter distribution of the concentrate, respectively.

In order to find a good operation parameter to satisfy the need of production enhancement and improve the smelting performance, a series of simulation study of the copper flash smelting process has been undertaken. Table 5 shows the partial operation parameter of the flash smelting furnace and simulation results.In table 4, the operation parameter 1 is the real condition used in the Jinlong flash smelting furnace before production enhance. Parameter 2 is used in Jinlong smelter after production enhancement without optimizing the operation parameter. This parameter has been proved to do harm to the wall of the RS. The detailed discussion of these two simulations is presented elsewhere [6]. Parameter 3 is the best operation parameter achieved from a series of numerical simulation. Compared with result of the parameter 1 and 2, the simulation result of parameter 3 has the highest particles temperature and smallest radius of particles distribution. It benefits for the particle melt and increasing the lifetime of RS.

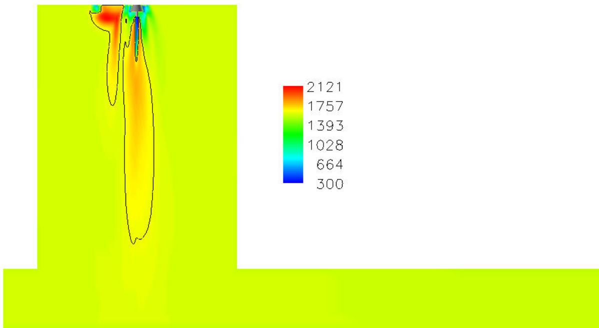

Figure 2: Temperature in Flash Smelting Furnace

The temperature distribution of simulation condition 3 in the flash smelting furnace is presented in Figure 2.

The highest temperature is 2121K. The temperature in the lower part of the shaft is more or less uniform, except near the central line of the flash shaft. However, in the upper part of the shaft, especially near the burner, large gradients exist. The contours in Figure 4 show that the temperature higher than 1650K. This zone lies at the center of the flash furnace under the CJD burner. This zone in simulation parameter 3 is the bigger than that of other operation parameters because of the effect of lower distribution air speed and higher ratio of O_c/O_o. Clearly, it benefits for the melting and reactions of concentrate particles..

	Weight/t·d^{-1}	Component/(%)					
		Cu	S	Fe	SiO_2	CaO	MgO
Copper concentrates	1573.03	30.22	30.53	25.73	7	0.5	0.5
Slag concentrates	37.75	22	8.6	33.05	14.45	–	–
SiO_2	171.95	–	–	1.0	96	–	–
FSF dust	104.3	26	12	25	5	–	–
WHB dust	15.48	53	16	15	5	–	–

Table 2: components of concentrate

2.8	3.9	5.5	7.8	11.	16.	22.	31.	44.	62.	88.	125	176
0.7	0.5	1.2	2.6	3.5	5.6	6.1	13.	17.	3.6	25.5	20.2	0

Table 3: Concentrate diameter distribution (μm)

NO.	Feed /t·h^{-1}	Oil for RS/kg·h^{-1}	Ratio of O_c/O_o	distributed air velocity /m·s^{1}	oxygen enrichment rate of process air	Highest tempera -ture of particle/K	Radius of particles distribution/m
1	69.5	468	0.10	180	0.55	1728	1.7
2	80	341	0.06	180	0.55	1838	1.69
3	80	341	0.11	130	0.55	1880	1.5

Table 4: partial simulation conditions and result

Almost all the particles seem to react in a very narrow region. This is seen more obviously from the mass fractions of O_2 and SO_2, show in Figures 3 and 4. After the oxygen-enriched air and the central oxygen is injected from CJD burner, the concentration of oxygen decreases rapidly. The SO_2 concentration is very high in all regions of the flash furnace, especially below the CJD burner, except for the area near the oxygen injector and oil burner. The maximum mass fraction of SO_2 is 77.5%.

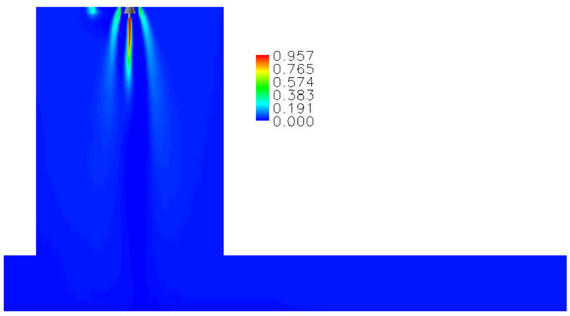

Figure 3: O_2 Content in Flash Furnace

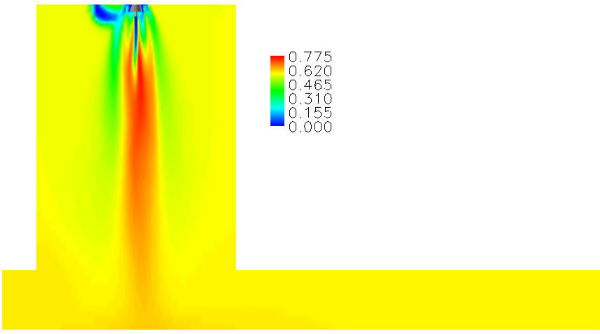

Figure 4: SO_2 Content in Flash Furnace

Figure 5 shows the particle trajectories and temperature. After the particles leave the CJD burner, they fall down with the process oxygen-enriched air and drop into the slag and matte layers at the bottom of the settler. Clearly, lower distribution air speed makes the concentration of particles and few particles hit the wall of RS directly. It benefit for the collision and reactions among particles, increasing the lifetime of RS and keeping the copper flash smelting furnace working in safe status. At the same time, few particles leave the flash smelting furnace, which means the decreasing of dust rate.

The particle temperatures are also shown in Figure 5. Particles are injected and heated to decomposition temperature by radiation and convection from oil combustion, the shaft wall and hot circulating gas. The highest temperature reached by the particles is 1880K and the peak temperature is higher than that of other simulation condition because of the lower distribution air speed and higher ratio of O_c/O_o. The higher temperature of particles is good for the melt and reaction of particles.

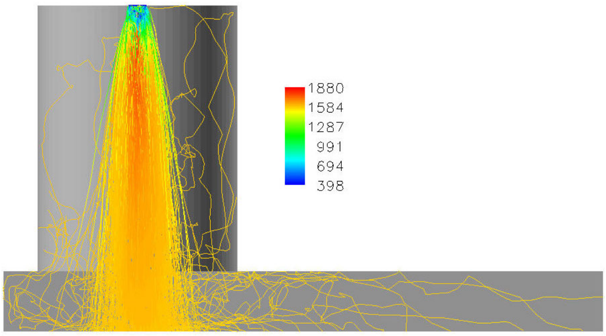

Figure 5: Particle Trajectories and Temperature

EFFECT OF OPTIMIZATION

Through numerical simulation, the production enhancement and operation parameter's optimization is achieved. Table 5 shows the improving of smelting performance in flash smelting furnace after optimization. The feed of the concentrate increased from 65 to 80 ton per hour. Dust rate decreased from 7.5% to less than 5.5%. Availability of the flash smelting furnace increased from 87% to 95%. Oil consumption decreased from 30 to less than 13.7 kg per ton concentrate. And the electric power consumption by the slag cleaning electric furnace (SCEF) decreased from the 80 to 50 kilo watt per hour.

	Availability of FSF	Dust Rate of FSF	Oil consumption	electric power consumption
July	0.87	0.075	30	80
Aug	0.91	0.073	29	60
Sep	0.85	0.057	26	54
Oct	0.94	0.056	22	44
Nov	0.97	0.051	15	47
Dec	0.965	0.053	13.6	46

Table 5: The improving of smelting performance in the flash smelting furnace after optimization

CONCLUSION

Numerical simulation has been used to optimize the product in flash smelting furnace. The conclusions can be summarized as follows:

- The study presented in this paper, shows that the reactions of concentrate take place in a very narrow place below the CJD burner.
- The concentration of the concentrate particles, concentration of oxygen and concentration of temperature are good for the smelting performance. This is named “the rule of 3C”.
- Numerical simulation and optimization is one of very effective methods for the production enhancement, the smelting performance improvement.

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